FADING, CODING AND MIMO-OFDM: A SHORT REVIEW

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Abstract—In Wireless communication, since free space is the medium for communication, it is essential to develop and implement efficient techniques to mitigate the effect of fading that occurs due to multipath propagation. Multi Input Multi Output (MIMO) technology provides diversity, which in turn helps to achieve higher data rates with better error performance. As the data rate increases, the type of fading becomes frequency selective which in turn causes Inter Symbol Interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM) combined with MIMO is the preferred technique in fourth generation wireless communication standards. Fading that occurs in wireless channel is equivalent to burst error in wired channel. Therefore the forward error correcting codes developed for wired channel can be used for wireless fading channel. This paper reviews work done in MIMO communication under different fading environment, considering various coding techniques and symbol mapping schemes. This survey also identifies the limitation and solution for immunizing MIMO communication in the presence of frequency flat and frequency selective fading conditions.

Index Terms—Fading channel, Forward error correcting code, Inter symbol Interference, MIMO-OFDM, Space-Time coding.

I. INTRODUCTION

The earlier generation of wireless cellular communication technology employs single antenna both at the transmitter and at the receiver, which results in point-to-point communication. This configuration is known as Single Input Single Output (SISO). The reliable communication depends on the signal strength. If the signal path is in deep fade, there is no guarantee for reliable communication. Since the channel capacity depends on the signal-to-noise ratio and the number of antennas used both at the transmitter and at the receiver, the capacity provided by SISO is limited. If the transmitted signal, passes through multiple signal paths, each path fades independently. Then there is a possibility that, atleast one of the path is strong, which ensures reliable communication. This technique is called “diversity” [1]. To achieve this, we need to use multiple antennas at the transmitter side and at the receiver side. This antenna configuration is called as Multiple Input Multiple Output (MIMO). As the data rate increases, the type of fading becomes frequency selective which in turn causes ISI. OFDM combined with MIMO is the most preferred technique in fourth generation wireless communication standards. OFDM technique converts the wide band channel into multiple narrow band channels, which in turn ensures that the fading across each of these narrow band is flat. Since fading due to multipath propagation in wireless channel can be modeled as burst mode error [2], the error control channel coding techniques developed for wired channel can be efficiently implemented for wireless flat fading channel. Higher order symbol mapping schemes such as 16-QAM, 64-QAM are used to map the coded data. As the order of mapping scheme increases, the symbols in the constellations are closely spaced. Hence large signal-to-noise ratio is required for reliable detection process at the receiver end.

II. FADING CHANNEL

The wireless channel is a multipath propagation channel. Multipath in the radio channel causes rapid fluctuation of signal amplitude, called small scale fading or simply fading. Fading is caused by destructive interference of two or more versions of the transmitted signal arriving at the receiver at slightly different times with different amplitudes and phases. Delayed signals are the result of reflections/scatterings from terrain features such as trees, hills, or mountains or objects such as people, vehicles or buildings. The received signal may vary widely in amplitude and phase over a short period of time or travel distance. Fading can be classified as frequency-flat and frequency-selective. If the signal bandwidth is lesser than the Coherence bandwidth, the fading is known as frequency-flat. If signal bandwidth is greater than the Coherence bandwidth of the channel, the fading is frequency-selective.

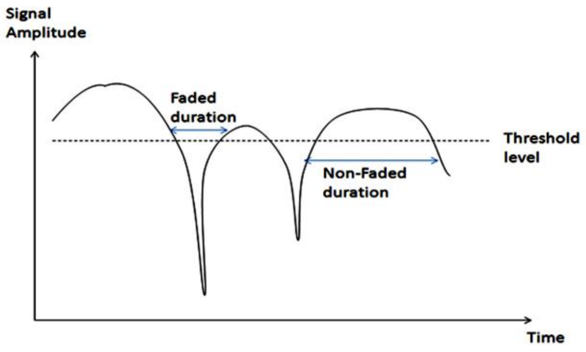

Fig. 1 Fading as a function of signal amplitude and time.

Statistical characterization of the variation of the envelope of the received signal over time leads to fading distributions. Two most common fading distributions we encounter are Rayleigh Fading and Rician Fading. If all the multipath components have approximately the same amplitude, the envelope of the received signal is Rayleigh distributed. No dominant signal component, such as line of sight component must exist. When there is a single dominant, stationary signal component present, the fading envelope is Rician. The Rician distribution slowly degenerates to Rayleigh when the dominant component fades away [3].The fading amplitude r_i at the Ith time instant can be represented as

$$r_i = \sqrt{(x_i + \beta)^2 + {y_i}^2}, \quad (1)$$

Where β is the amplitude of the specular component and x_i, y_i are samples of zero-mean stationary Gaussian random process with variance σ_o^2 . The ratio of specular to diffuse energy defines the Rician K-factor, which is given by $K = \beta^2/2\sigma_o^2$. The Rician PDF is given by

$$f_{Rice}(r) = \frac{r}{\sigma_o^2} \exp\left[-\frac{r^2 + \beta^2}{2\sigma_o^2}\right] I_o \left[\frac{r\beta}{\sigma_o^2}\right]$$

(2)

Where I_o [.] is the zero-order modified Bessel function of the first kind and r ≥ 0. Now if there is no dominant propagation path, K = 0, and I_o [.] = 1 yielding Rayleigh PDF

$$f_{Rayleigh}(r) = \frac{r}{\sigma_o^2} \exp\left[-\frac{r^2}{2\sigma_o^2}\right] \quad (3)$$

III. IMPORTANCE OF ERROR DETECTION AND CORRECTION

Error detection and correction are techniques that enable reliable delivery of digital data over unreliable communication channels. Many communication channels are subject to channel noise, and thus errors may be introduced during transmission from the source to a receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data. The general idea for achieving error detection and correction is to add some redundancy (i.e., some extra data) to a message. The parity bits are added in a known fashion, which is to be known both to the encoder and the decoder. The Shannon theorem states that given a noisy channel with channel capacity C and information transmitted at a rate R, then there exists a coding technique, that allow the probability of error at the receiver to be made arbitrarily small. This means that, theoretically it is possible to transmit information at a rate below the capacity C, without error [4]. This rate depends on the noisiness of the channel.

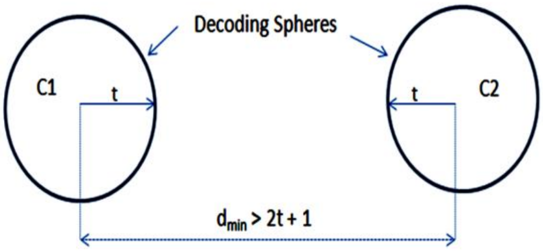

Fig. 2 Error Detection and Correction using Decoding sphere

Error-correcting codes are usually distinguished between convolutional codes and block codes: Convolutional codes are processed on a bit-by-bit basis and the Viterbi decoder allows optimal decoding. Block codes are processed on a block-by-block basis. Examples of block codes are Hamming codes, Reed-Solomon codes and Low-Density parity check code (LDPC). A code having a minimum distance *dmin* is capable of correcting all patterns of errors $t = [(dmin - 1)/2]$ or fewer errors in a code word, and is referred to as a random error correcting code.

In block codes, to detect t errors per block, the minimum distance of the block code should be $dmin \geq t+1$. *i.e.,* $t \leq dmin - 1$ errors can be detected. If the number of errors is equal to *dmin*, then one of the two codewords which form the pair for minimum distance might get changed into the other codeword. Hence the number of errors less than *dmin*, can be detected, because it will not make any codeword into another codeword. It takes *dmin* changes to transform from one codeword to another codeword. Similarly, to correct *t* errors per block, we must have $dmin \geq 2t+1$. Considering fig.2, the codewords *C1* and *C2* are spatially separated by the minimum distance *dmin*. i.e, if the number of errors occurs in *C2* is equal to *dmin*, then *C2* is transformed to *C1*. If *t* errors make the decoding sphere boundary around the codewords *C1* and *C2*, and if the circumference of these two spheres touch each other, the $dmin = 2t$. In this case, if any t error occurs, the erroneous codeword can be mapped to the codeword corresponding to the decoding sphere. If the erroneous codeword is exactly t distance from $C1$ and t distance from $C2$, the correct decision cannot be made. To avoid this ambiguity, the condition for correcting t errors per block should be $dmin \geq 2t + 1$. When these two decoding spheres intersect, the decoding will be incorrect. In order to increase the error correcting capability of a block code, the minimum distance should be larger [5].

Bit interleaving is a well-known technique for dispersing the errors that occur in burst when the received signal level fades, and which are likely to exceed the correcting capability of a code. Before a message is transmitted, the entire bit stream is interleaved. With interleaving, the burst mode error is converted to dispersed error. Hence, the coding schemes designed to correct random or dispersed error can be used to correct burst mode error with interleaving. Note that the interleaving process does not involve adding redundancy. Concatenated coding schemes are used to provide even more protection against bit errors than is possible with a single coding scheme.

IV. MIMO COMMUNICATION

In wireless communication, multiple antennas can be utilized in order to build redundancy and hence enhance the bit rate, and signal-to-noise-plus-interference ratio of wireless systems. Sensitivity to fading is reduced by the spatial diversity. In a MIMO system, given total transmission power can be divided among multiple spatial paths. Conventional single-antenna transmission techniques aiming at an optimal wireless system performance operate in the time domain and/or in the frequency domain. With MIMO, spatial domain is exploited by using space-time coding to overcome the detrimental effects of multipath fading.

A] Channel Capacity

For a Single-Input Single-Output antenna system, the capacity is given by $C = log (1+SNR)$. With MIMO, the capacity is $C \approx m. log (1+SNR)$, where m is the minimum number of antennas in the transmitter and receiver sides.

B] Higher Bit Rates with Spatial Multiplexing

Spatial multiplexing techniques simultaneously transmit independent information sequences, over multiple antennas. Spatial Multiplexing takes the high rate signal and breaks it down to lower rate streams. Using M transmit antennas, the overall bit rate compared to a single-antenna system is thus enhanced by a factor of M without requiring extra bandwidth or extra transmission power. Since the individual data streams are superimposed during transmission, they have to be separated at the receiver using an interference cancellation type of algorithm (typically in conjunction with multiple receive antennas). Spatial multiplexing scheme can be implemented with Bell-Labs Layered Space-Time Architecture (BLAST) [1].

C] Enhancing Error performance through Space-Time coding

Similar to channel coding, multiple antennas can also be used to improve the error rate of a system, by transmitting and/or receiving redundant signals representing the same information sequence. By means of two-dimensional coding in time and space, commonly referred to as space-time coding, the information sequence is spread out over multiple transmit antennas. At the receiver, an appropriate combining of the redundant signals has to be performed. Optionally, multiple receive antennas can be used, in order to further improve the error performance (receiver diversity). The advantage over conventional channel coding is that redundancy can be accommodated in the spatial domain, rather than in time domain. Well-known spatial diversity technique for systems with multiple transmit antennas is Alamouti’s transmit diversity scheme [6].

V. MIMO-OFDM

Broadband wireless systems encounter large delay spread, and, therefore, have to cope with frequency-selectivity. Fig.3 shows a schematic of OFDM transmission over a SISO channel. OFDM extends directly to MIMO channels with the IFFT/FFT and CP operations being performed at each of transmit and receive antennas. The schematic of MIMO-STBC-OFDM is shown in Fig.4.The use of MIMO-OFDM decouples the frequency-selective MIMO channel into a set of parallel frequency-flat MIMO channels. Orthogonal frequency division multiplexing technique, splits the data to be transmitted along the orthogonal narrowband carriers well spaced by frequency. The technique used for splitting the data is Inverse Fast Fourier Transform (IFFT) which incorporates the advantage of transmitting the data at a higher rate. The introduction

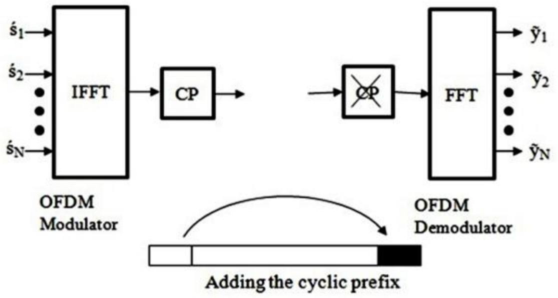

Fig. 3 SISO - OFDM

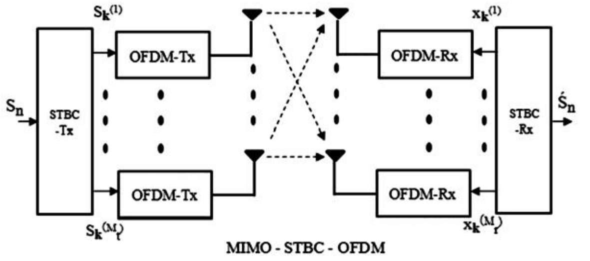

Fig. 4 MIMO - STBC - OFDM

of cyclic prefix (CP) in terms of guard interval consists of repetition of the last part of the symbol at the beginning of each symbol transmitted. This avoids interference between the various symbols and the carriers, if the CP interval is longer than the delay caused by the interferences of the channel. This improves the robustness of the technology used for the multipath transmission. The use of narrowband subcarrier is to get a channel which is constant for each sub-band. This avoids synchronization problems at the receiver side during the symbol transmission through the channel. In order to get high spectral efficient system, overlapping between the mutually orthogonal subcarrier is allowed. A MIMO system can improve the capacity by a factor of the minimum number of transmit and receive antennas for flat fading or narrow-band channels. For wideband transmission, it is natural to combine OFDM with space–time coding (STC) to deal with frequency selectivity of wireless channels and to obtain diversity and/or capacity gains. Therefore, MIMO-OFDM has widely been used in various wireless systems and standards [7].

VI. LITERATURE SURVEY

A] MIMO-STBC

In [8], authors have considered a slow Rayleigh fading SISO link and evaluate the performance of turbo code without any concatenation scheme. They find at low SNRs the code rate significantly influences the error performance. In [9], the concatenation of Convolutional Code (CC) with Reed-Solomon (RS) has been considered for SISO under AWGN channel. It is shown that concatenation improves the error performance, and the outer code should be a block code which can handle burst error and the inner code should be a CC which can correct random errors. [10] considers only transmit diversity (MISO) in the presence of flat fading with single code rate and BPSK symbol mapping. Coding schemes considered here are CC and Turbo code (TC). They show that (a) use of interleaving between outer and inner code improves the error performance; (b) outer code must have maximum hamming distance to achieve coding gain.

In [11], the author evaluates the performance of concatenation of CC with STBC under MISO system in the presence of Rayleigh flat fading. They consider only code rates below 0.5 which provide more redundancy and find that coding gain increases with code rate. In [12], the work evaluates the performance of concatenating LDPC with MIMO-STBC and [13] describes parallel concatenation of TC with STBC. These two efforts show that the error performance improves as the number of transmit and receive antenna increases. They do not deal with the effect of code rates. In [14], the error performance analysis is carried out in the presence of MIMO and MISO flat fading Rayleigh channel with concatenation of CC and TC with STBC. The code rates of CC and TC used here are 0.5, 0.75 and 0.83. Various symbol mapping schemes such as BPSK, QPSK, 8PSK, 16QAM and 64QAM have been considered. It is shown that the channel code followed by an interleaver improves the error performance. The concatenation of STBC with TC provides the highest coding gain. It is also clear that at low Eb/No, coding does not help in improving BER.

In [15] the error analysis is done with concatenation of cyclic codes and Hamming codes with STBC under MIMO and MISO flat fading Rayleigh channel and BPSK symbol mapping scheme. It is learnt that as code rate increases the error performance worsens. [16] evaluates error performance under MIMO and MISO frequency selective Rayleigh fading with the concatenation of ½ rate CC, followed by an interleaver with STBC. The symbol mapping schemes used are BPSK and QPSK. It is shown that, for higher order symbol mapping schemes, the required Eb/No to improve the error rate increases.

B] MIMO-STBC-OFDM

In [17], the work concludes that BER improves with increase in the number of receive antennas and the error performance degrades with increase in the number of subcarriers because of interference between the subcarriers. They use MIMO-1x2,2x2,2x3,2x4 antenna configurations, Rayleigh fading, BPSK symbol mapping and CC with 1/2 rate. Simulations are carried out with different numbers of OFDM subcarriers : 16,32,64,128. Work [18] shows that, as the number of resolvable paths increases, MIMO2x2-OFDM-BPSK performs better than the other multiple antenna configurations. The various antenna configurations used are MISO 2x1, MIMO2x2-OFDM and MISO2x1 w/o OFDM, under Rayleigh fading with CC-1/2 rate followed by an interleaver. The symbol mapping schemes considered are BPSK and QPSK.

In [19], it is shown that LDPC coding technique outperforms convolutional coding (CC) and the best performance is achieved with the antenna configuration

MISO-4x1 compared to MISO 2x1 and MIMO 2x2 for all symbol mapping schemes. The symbol mapping schemes and code rates considered are BPSK-1/2, QPSK-2/3, 16-QAM-3/4, 64-QAM-5/6. In [20], the work compares coded OFDM and uncoded OFDM with two different delay spreads. It is shown that, coded OFDM outperforms uncoded OFDM for both the values of delay spread. The system configuration considered are MISO4x1, MISO2x1 with CC-1/2 rate and QPSK symbol mapping scheme. In [21], authors have considered MIMO2x2 with Rayleigh fading. Coding schemes considered are CC [7,5] (outer code) and Golay code [23,12,7] (inner code). Symbol mapping schemes considered are QPSK, 16-QAM and 64-QAM. It is shown that the concatenation of CC with Golay performs better than with having only CC [7,5]. Though they mention considering HC with different code rates viz. [7,4,3], [15,11,3], these results are not shown. Results for CC with various symbol mapping schemes show that error increases as the order of the symbol mapping scheme increases.

Different ways of implementing coding and interleaving techniques are described in [22], with a MIMO2x2 (no STBC) and 192 OFDM sub carriers, CC with code rates – ½ and 3/4 followed by an interleaver for symbol mapping schemes of BPSK-1/2, QPSK-3/4, 16-QAM-3/4 and 64-QAM-3/4. Result shows that cross-antenna coded with per-antenna interleaver scheme performs well for all symbol mapping schemes. In [23], MIMO2x2 antenna system, OFDM with 1024 sub channels (out of which only the middle 751 sub carriers carry data), Rayleigh fading and the symbol mapping schemes 16-QAM, 256-QAM are considered. Here outer code is Turbo code (TC) with code rate 3/4 and inner code is CC with rate 2/3 followed by an interleaver. This work compares the simulation results of serially concatenated CC (SCCC) with parallel concatenation of CC (PCCC) performance. It is shown that 1/2 rate PCCC with ML detection performs better than SCCC.

In [24], authors talk about Transmit Selection Diversity (TSD) algorithm for adaptive high-data rate concatenated coding scheme (CC1/2-STBC). Comparison of MIMO2x2-STBC-OFDM (167 subcarriers) and TSD with and w/o CC-1/2 rate, 4-QAM, 16-QAM, 64-QAM is made. In both cases, it shown that TSD w/ and w/o CC performs better than STBC w/ and w/o CC. In [25], the work compares the performance of MIMO2x2 and MIMO4x4 with OFDM and QPSK, LDPC-1/2 rate. Maximum aposteriori (MAP) demodulator and Linear Minimum Means Square Error Soft-interference Cancellation (LMMSE-SIC) demodulator are considered. Compared with the receiver, which employs MAP demodulation, the receiver employing a LMMSE-SIC demodulator has limited performance loss (less than 1 dB) in spatially uncorrelated channels but suffers extra performance loss in spatially correlated channels. In [26], many combinations of multiple antenna systems are considered along with 128 OFDM subcarriers, BPSK, QPSK, 16QAM, 64-QAM and TC with code rates 1/2, 2/3 and 3/4. Type of fading is not specified, but in their simulations, an assumption is made that the received signals are corrupted by AWGN. It is shown that with 16-QAM, MIMO 3x5, the system yields best performance compared to other MIMO configurations. This work also compares the performance of BER with and without the MSE joint detection technique at the receiver by considering DQPSK, CC - 1/2 rate and Rayleigh fading. It is shown that joint detection with MSE normalization algorithm performance is better than the other scheme.

VII. CONCLUSION

The importance of mitigating fading in wireless communication to achieve higher data rate, the role of error control coding techniques and symbol mapping schemes for MIMO fading channel were reviewed. From literature survey, it is observed that, by considering various coding and symbol mapping schemes under flat fading condition, significant enhancement in bit error performance and coding gain can be achieved by MIMO-STBC technique. It is also reviewed that, in the case of frequency-selective fading, MIMO-STBC-OFDM technique with various coding and symbol mapping schemes, offers improvement in error performance by eliminating the effects of ISI.

REFERENCES

[1] David Tse, Pramod Viswanath, “Fundamentals of Wireless Communication”,Cambridge University press 2005.

[2] Shu Lin, Daniel J.Costello,Jr.,’Error Control Coding’, Pearson, 2nd edition.

[3] Theodore S.Rappaport, ’Wireless Communications – Principles and Practice’, Pearson second edition.

[4] Simon Haykin, 'Digital Communications', John Wiley & Sons Ltd, edition-2006.

[5] www.nptel.com.

[6] Siavash M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications ", IEEE journal on select areas in communications, vol. 16, no. 8, October 1998.

[7] Taewon Hwang, Chenyang Yang, Gang Wu, Shaoqian Li and Geoffrey Ye Li, “OFDM and Its Wireless Applications: A Survey”, IEEE Transactions on Vehicular Technology, Vol.58, No.4, May 2009.

[8] Fulvio Babich, Senior Member, IEEE,’On the Performance of Efficient Coding Techniques over Fading Channels’, IEEE Transactions on Wireless Communications, Vol.3, No.1, January 2004.

[9] Sanjeev Kumar, Ragini Gupta, “Performance Comparison of Different Forward Error Correction Coding Techniques for wireless Communication systems,” IJCST, vol. 2, Issue. 3, September 2011.

[10] Harsh Shah, Ahmadreza Hedayat, Member, IEEE, and Aria Nosratinia, Senior Member, IEEE," Performance of Concatenated Channel Codes and Orthogonal Space-Time Block Codes", IEEE transactions on wireless communications, vol. 5, no. 6, June 2006.

[11] Wei Ning An,Walaa Hamouda, Senior Member of IEEE, “Reduced Complexity Concatenated code in Fading Channels,” IEEE Communication Letter, vol. 15, no. 7, July 2011.

[12] Jingqiao Zhang, Student Member ,IEEE, and Heung-No Lee, Member, IEEE, ‘Performance analysis on LDPC-Coded systems over Quasi-Static(MIMO) Fading channels’, IEEE Transactions on Communications, vol.56, no.12, December 2008.

[13] Dongzhe Cui and Alexander M. Haimovich, Senior Member, IEEE, "Performance of Parallel Concatenated Space–Time Codes", IEEE communications letters, vol. 5, no. 6, June 2001.

[14] T.H.Liew and Lajos Hanzo,”Space-Time codes and concatenated channel codes for wireless communications”, Proceedings of IEEE, vol.90, no.2, February 2002.

[15] Almas Uddin Ahmed, Nowshad Amin, Hafizal Mohamad,Md.Shabiul Islam, Nor Azhar Mohd Arif,”Code rate – Diversity tradeoff with Linear Block codes for MIMO wireless systems ”,Proceedings of the International Conference on Computer and Communication Engineering 2008.

[16] Tung X.Lai, Tuan A.Tran and Abu B.Sesay, “Performance Analysis of Space Time Block Coded Systems over Frequency Selective Rayleigh Fading Channels”, IEEE-WCNC 2006 proceedings.

[17] Jiang Xuehua,Chen Peijiang, "Study and Implementation of MIMO-OFDM system based on Matlab", IEEE computer society - International conference on Information Technology and Computer Science, 2009.

[18] Hesham El Gamal, A.Roger Hammons, "On the Design of Space-Time and Space-Frequency codes for MIMO Frequency-Selective fading channels", IEEE Transactions on Information Theory, Vol.49, No.9, September 2003.

[19] Salwa Serag Eldin, Mohamed Nasr, Salah Khamees, "LDPC coded MIMO OFDM based IEEE 802.11n Wireless LAN", IEEE-978-1-4244-3474-9/09/2009.

[20] N.K.Noordin,B.M.Ali,S.S.Jamuar and M.B.Ismail, "Coded Space-Time-Frequency OFDM over IEEE 802.11 Fading channels", 2005 Asia-Pacific Conference on Communications, October 2005.

[21] Lucian Andrei Perisoara, Mihai Neghina, Rodica Stoian, "Performances of FEC Coded MIMO OFDM Systems", IEEE-1-4244-2420-7/08-2008.

[22] Zafar Iqbal, Saeid Nooshabadi, and Heung-No Lee, "Analysis and Design of Coding and Interleaving in a MIMO-OFDM Communication system", IEEE Transactions on Consumer Electronics, Vol.58, No.3, August 2012.

[23] Xiangyang Zhuang, Frederick W.Vook, and Timothy A.Thomas, "OFDM Multi-Antenna Designs with Concatenated codes", IEEE-0-7803-7632-3/02-2002.

[24] A.S.Gallo,E.Bizzarri, G.M.Vetetta and M.Marciniak, "A Comparison of Inner Coding options for Adaptive MIMO OFDM Systems", ICTON 2003, We.P.15.

[25] Ben Lu, Guosen Yue and Xiaodong Wang, "Performance Analysis of LDPC MIMO OFDM Systems", IEEE Transactions on Signal Processing, Vol.52,No.2, February 2004.

[26] Luca Giangaspero and Luigi Agarossi, Giovanni Paltenghi, "Co-Channel Interference Cancellation based on MIMO OFDM Systems", IEEE wireless Communications article - 1536-1284/02-2002.

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